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Nikkhoo et al.

(10) **Patent No.: US 10,028,418 B2**
(45) **Date of Patent: Jul. 17, 2018**

(54) **METAL ENCASED GRAPHITE LAYER HEAT PIPE**

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(22) Filed: **Jan. 20, 2015**

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(51) **Int. Cl.**
H05K 7/20 (2006.01)
G02B 27/01 (2006.01)
G02B 7/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H05K 7/20963*** (2013.01); ***G02B 7/008*** (2013.01); ***G02B 27/0176*** (2013.01); *G02B 2027/0178* (2013.01)

(58) **Field of Classification Search**
CPC G02B 2027/0178; G02B 27/0176; G02B 7/008; H05K 7/20963
USPC 359/630; 361/709
See application file for complete search history.

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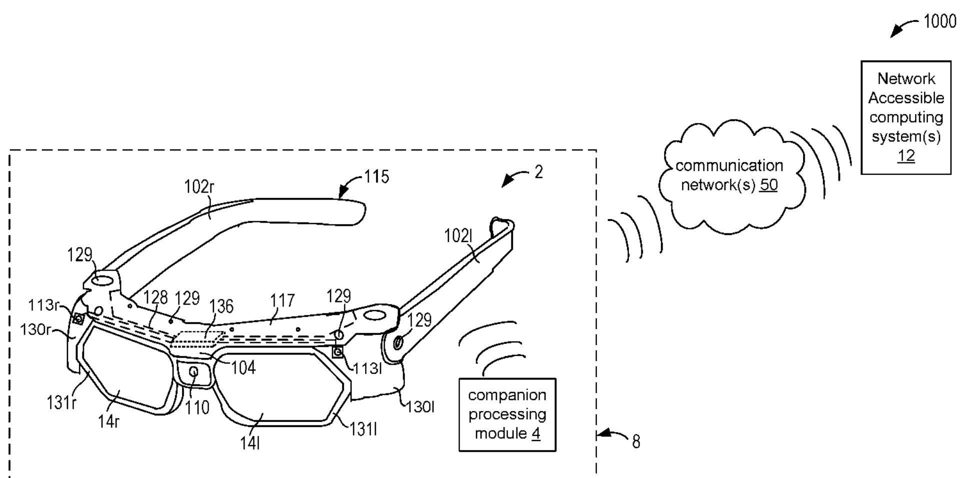
(57) **ABSTRACT**

A metal encased multilayer stack of graphite sheets used as a passive thermal conductor. In the stack, each sheet has a plane high thermal conductivity along a first axis and a plane of lower thermal conductivity along a second axis. The stack is created to have a three-dimensional shape including a length and a width, and the first axis is aligned parallel to said length, the multilayer stack having a height less than the width. A first metal structure surrounds the multilayer stack of graphite sheets, with the metal structure encasing the multilayer stack along the length, width and height of the multilayer stack.

20 Claims, 9 Drawing Sheets



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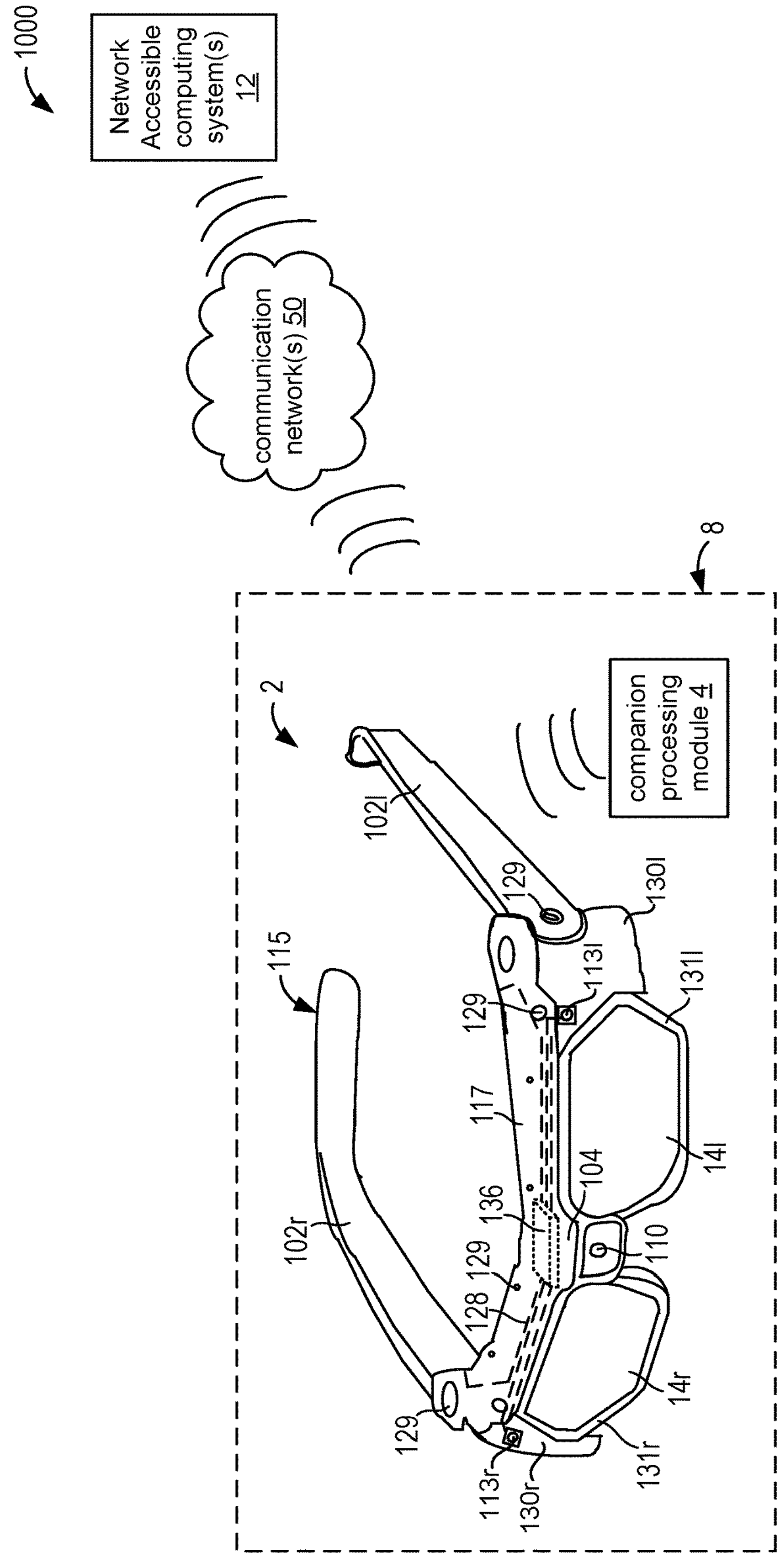
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communication network(s) 50
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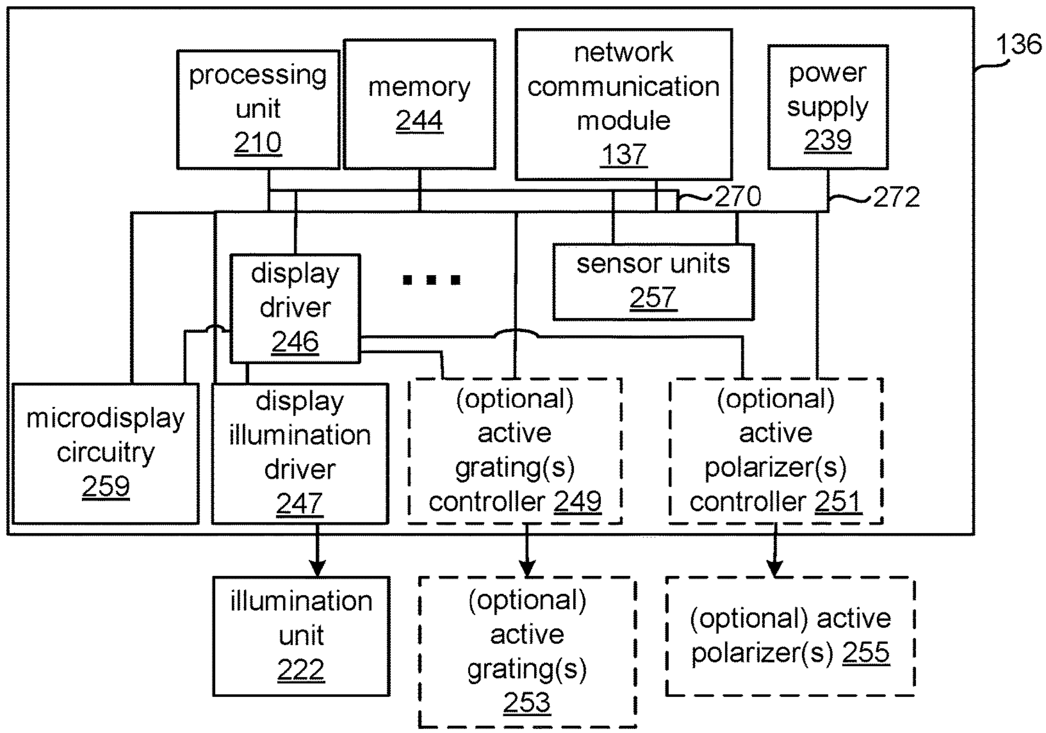
FIG. 1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power supply 239
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display illumination driver 247
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(optional) active polarizer(s) 255

FIG. 2A

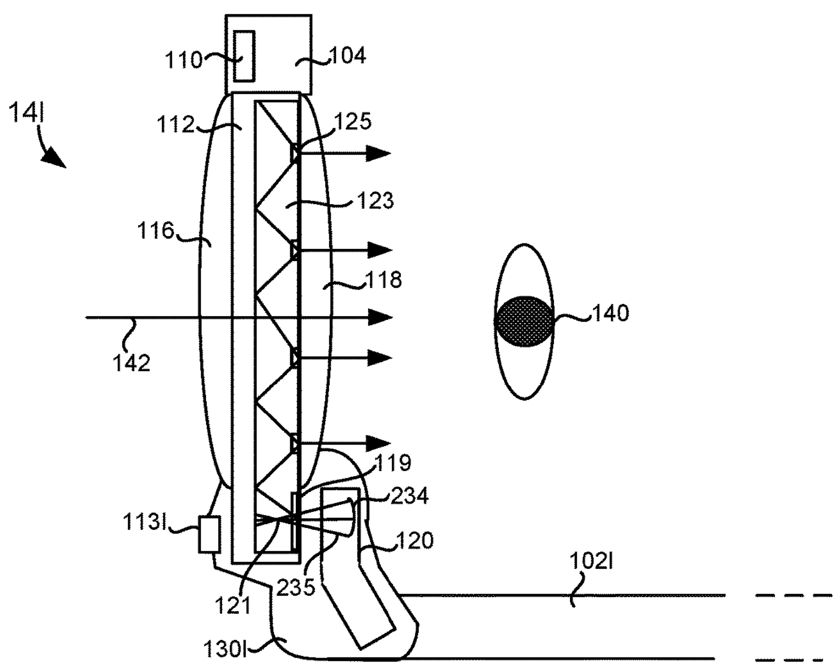
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FIG. 2B

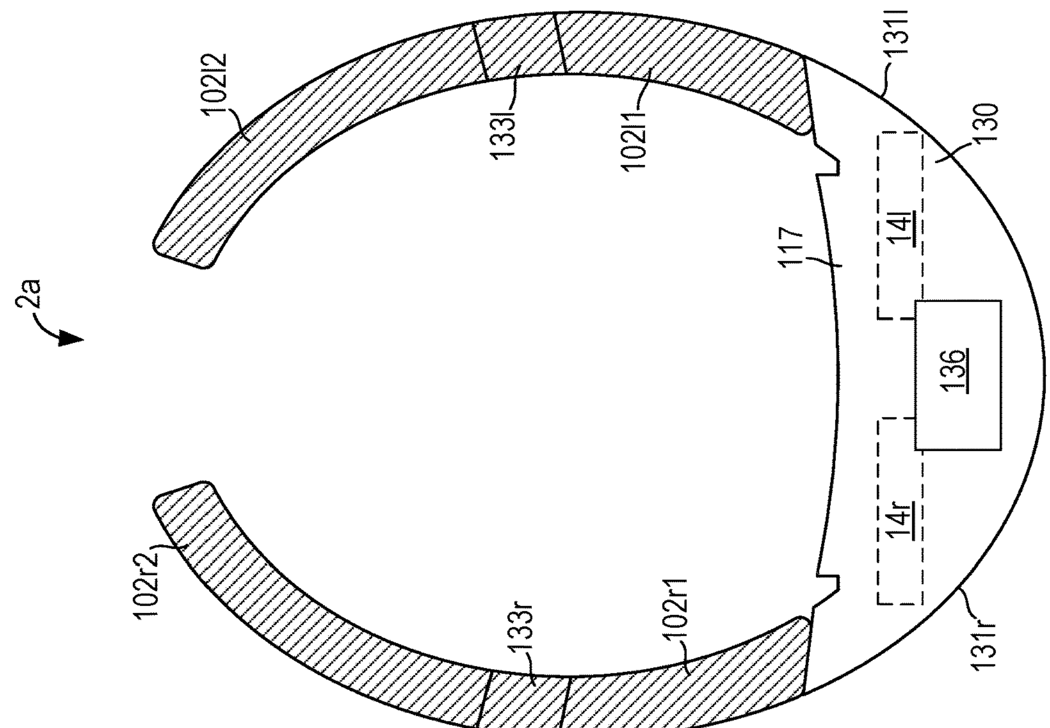

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FIG. 3B

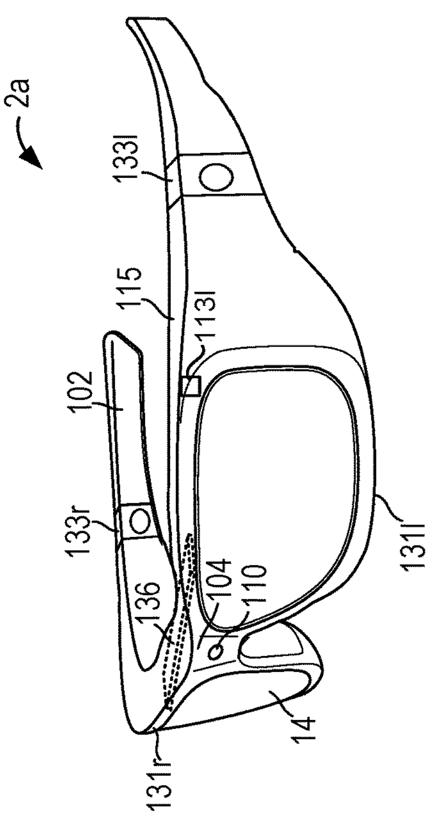

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FIG. 3A

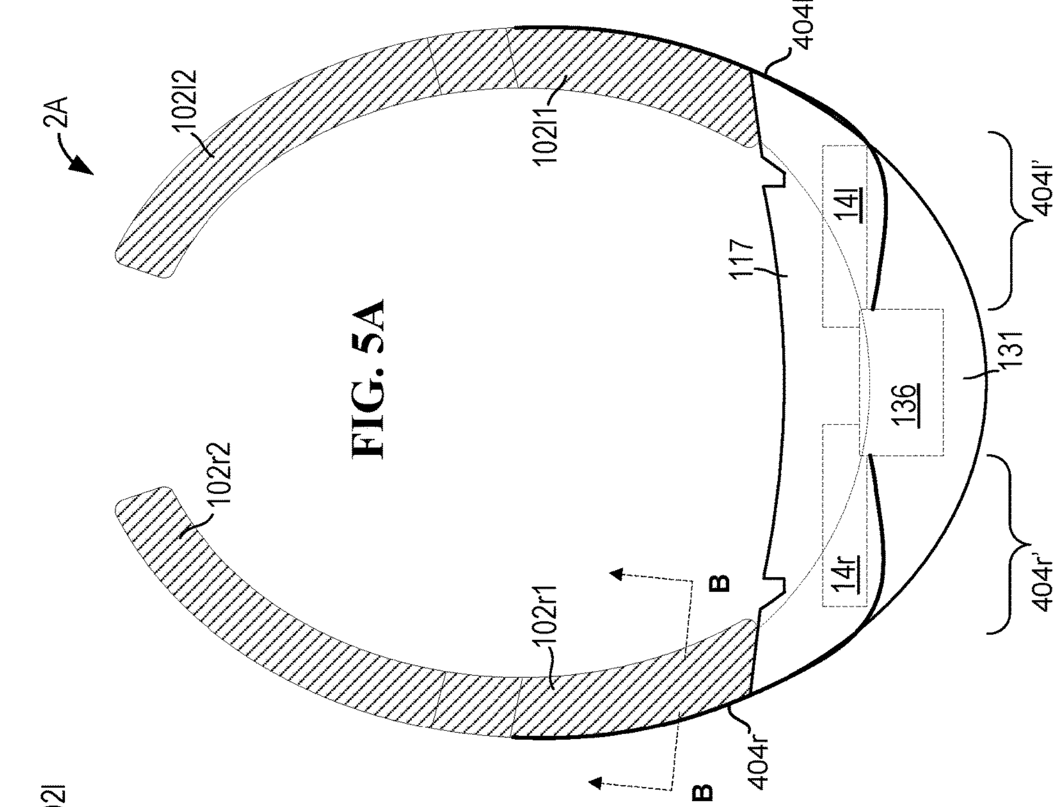


FIG. 5A

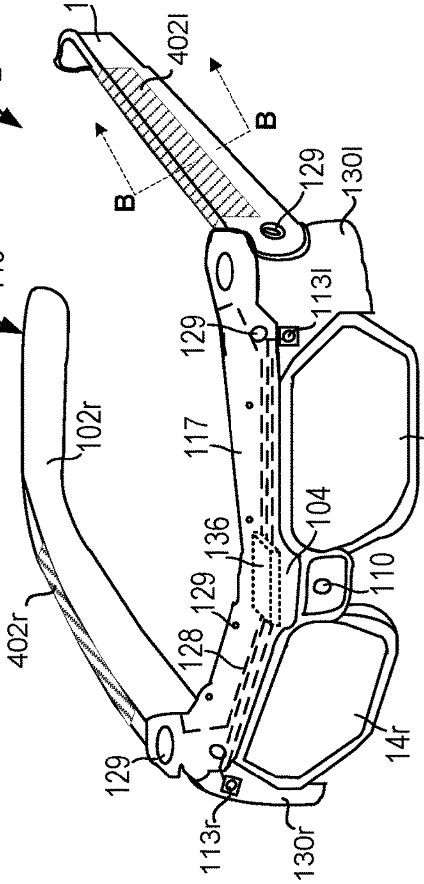


FIG. 4A

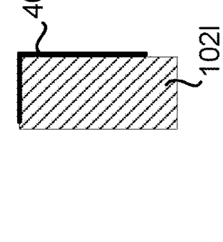
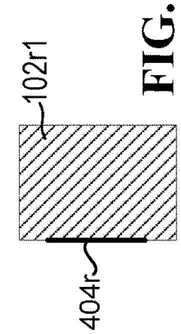


FIG. 4B



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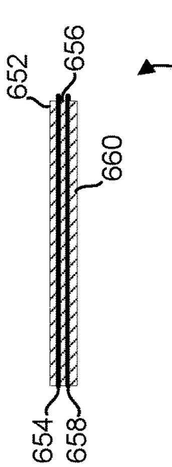
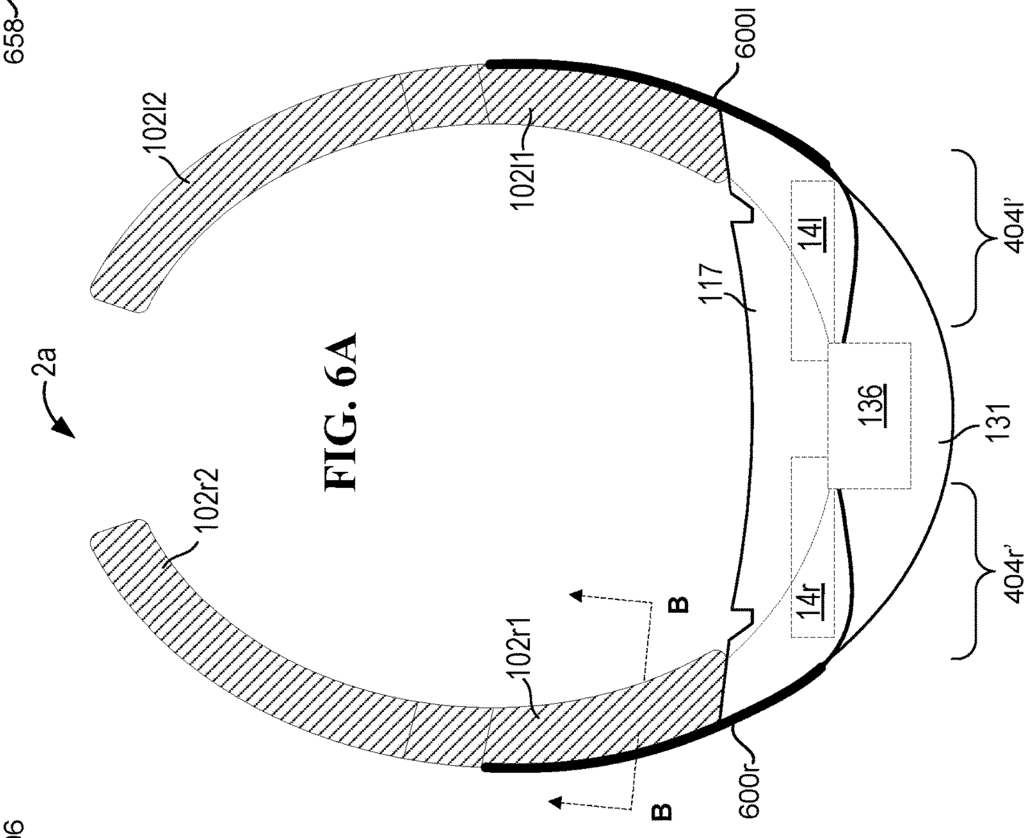


FIG. 6D



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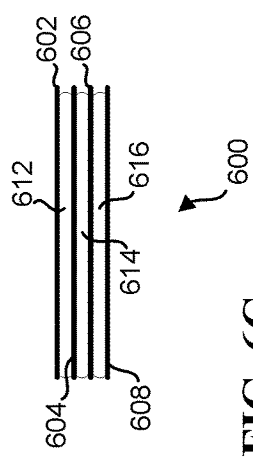


FIG. 6C

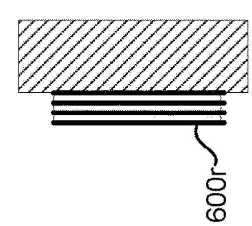


FIG. 6B

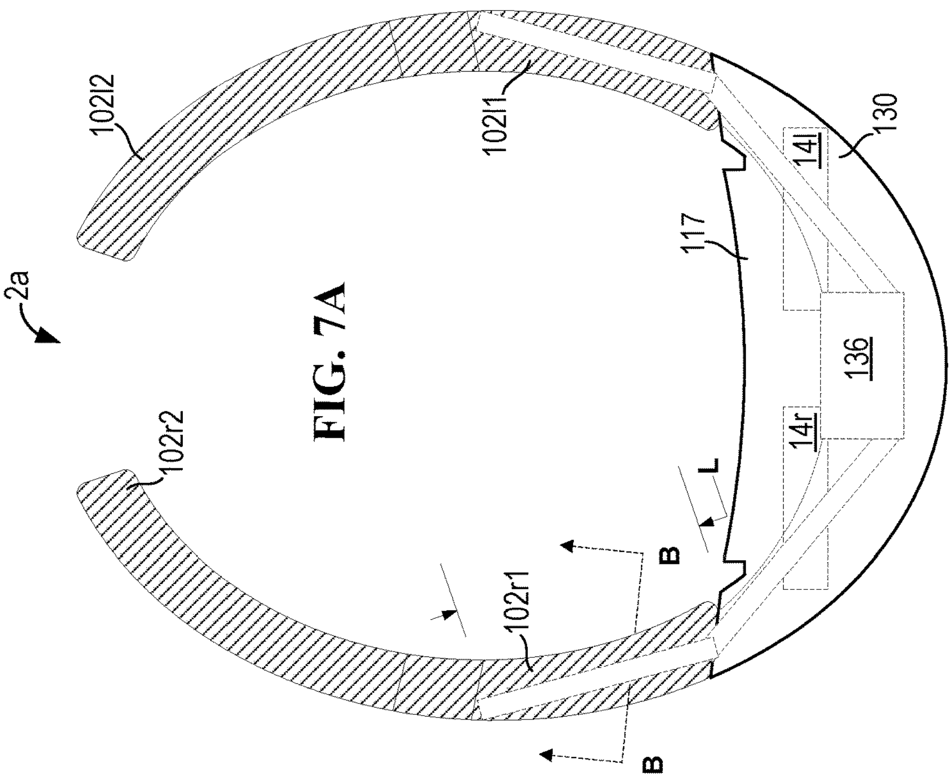


FIG. 7A

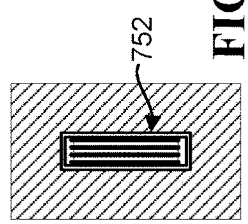
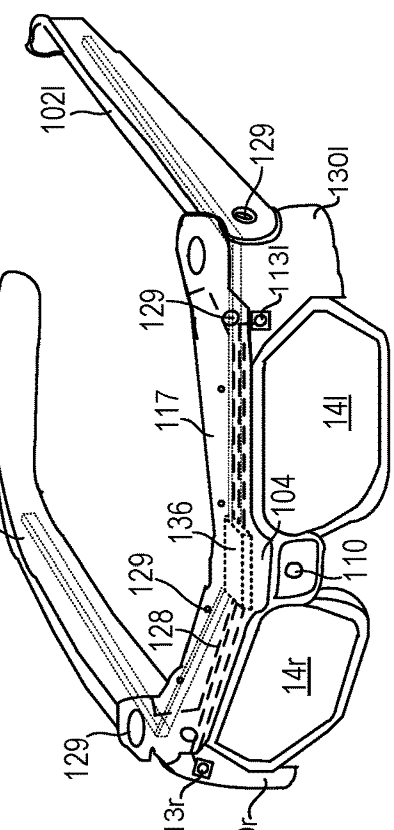


FIG. 7B



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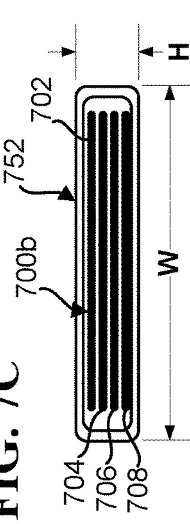


FIG. 7C

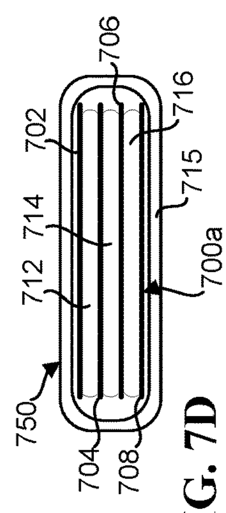
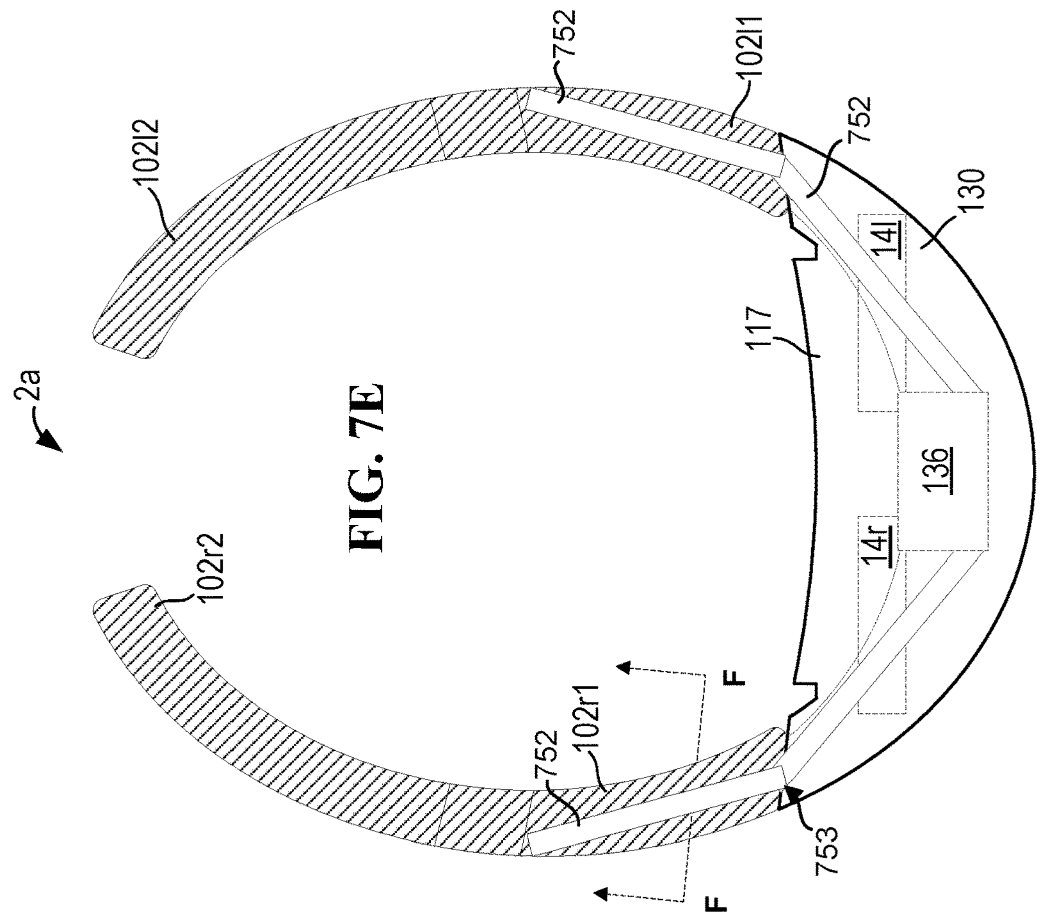


FIG. 7D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102r1
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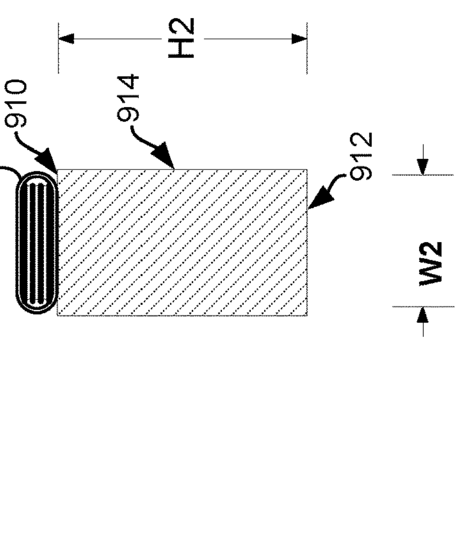
753
F

FIG. 7E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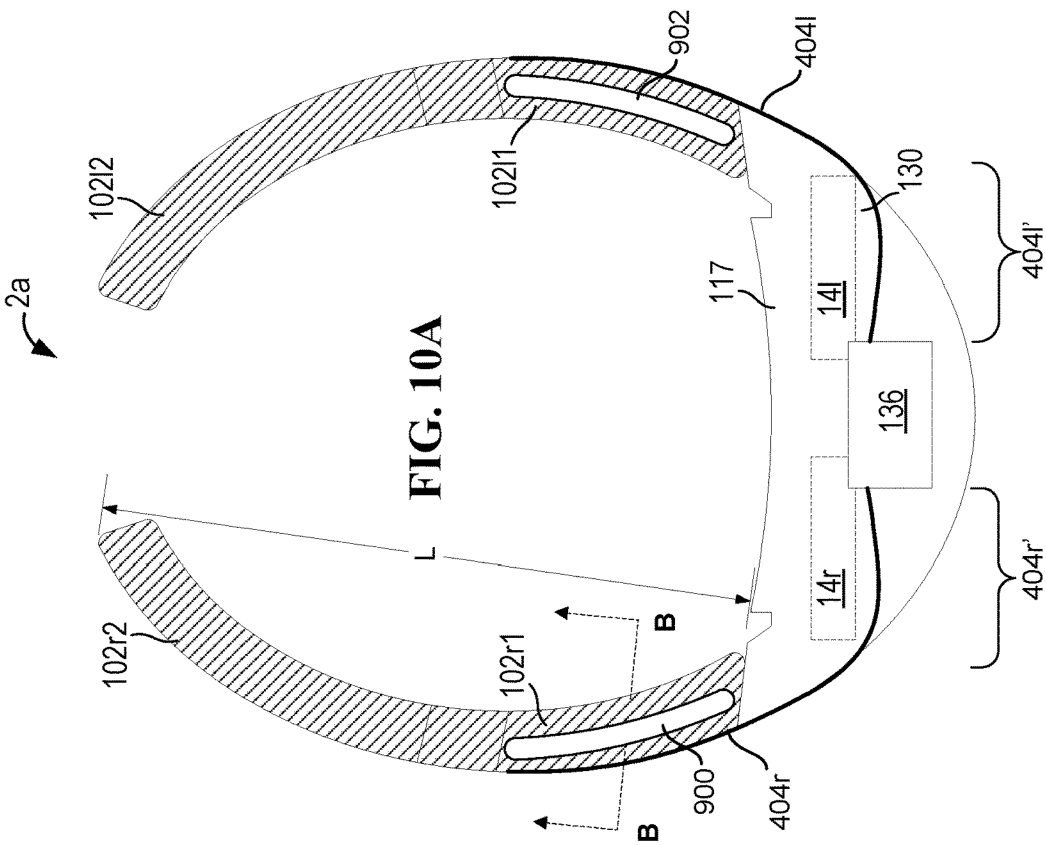
912
W2

FIG. 7F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902
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404l'
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136
14r
404r'
L
B
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900
404r

FIG. 10A

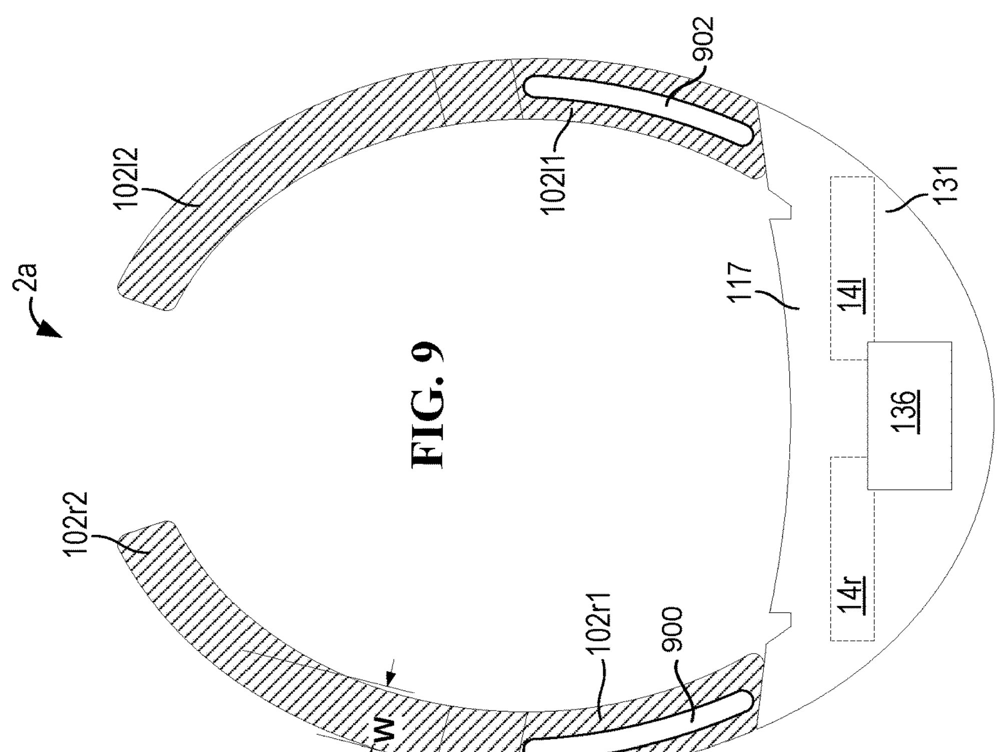
2a
102l2
102l1
902
131
117
14l
136
14r
102r2
102r1
900
W

FIG. 9

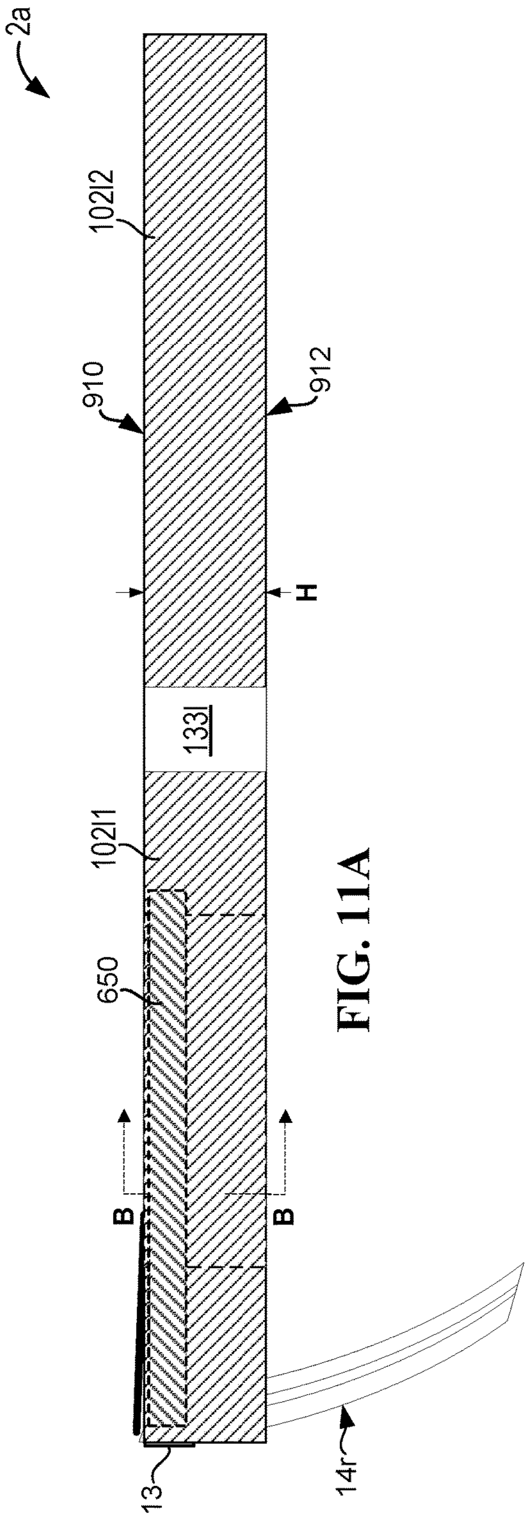

FIG. 11A

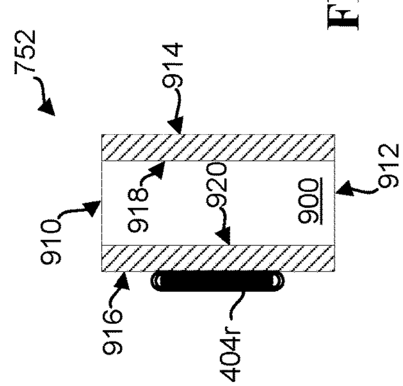

FIG. 10B

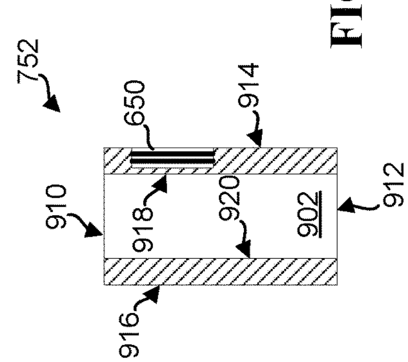

FIG. 11B

METAL ENCASED GRAPHITE LAYER HEAT PIPE

BACKGROUND

A see-through, mixed reality display device system enables a user to observe digital information overlaid on the physical scenery. To enable hands-free user interaction, a see-through, mixed reality display device system may further be equipped with an eye tracker, sensors and displays, all of which are sensitive to mis-alignment if the optical platform or frame on which they are mounted distorts. Like all devices which include electronic components, the components produce heat which must be redistributed to areas of the device that are not adjacent to the components. This ensures proper component operation and optical platform stability.

SUMMARY

The technology, briefly described, includes a metal encased multilayer stack of graphite sheets which may be advantageously used as a passive thermal conductor. In the stack, each sheet has a plane high thermal conductivity along a first axis and a plane of lower thermal conductivity along a second axis. The stack is created to have a three-dimensional shape including a length and a width, and the first axis is aligned parallel to said length, the multilayer stack having a height less than the width. A first metal structure surrounds the multilayer stack of graphite sheets, with the metal structure encasing the multilayer stack along the length, width and height of the multilayer stack. The technology is optionally used in an optical mounting structure including heat generating electronic components and housing a display optical system coupled to the electronics. The optical mounting structure may include first and second temple arms extending away from the heat producing electrical components and the display optical systems. The metal encased multilayer stack of graphite sheets is thermally bonded to the heat producing electrical components and to an exterior surface of the optical mounting structure. The technology can be used with any electronic components, including high power components, in an optical system or any electronic device.

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram depicting example components of an embodiment of a near-eye display (NED) device system.

FIG. **2**A is a block diagram of example hardware components in a control circuitry embodiment of a NED device.

FIG. **2**B is a top view of a near-eye display embodiment being coupled with a projection light engine having an external exit pupil.

FIG. **3**A is a perspective view and FIG. **3**B is a top view of a second example of a head mounted display embodiment of a near-eye display device system.

FIG. **4**A is an example of a first thermal management solution including a bonded graphite layer attached to a head mounted display.

FIG. **4**B is a cross section along lines B-B in FIG. **4**A.

FIG. **5**A is an example of the first thermal management solution including a bonded graphite layer attached to another embodiment of a head mounted display.

FIG. **5**B is a cross section along lines B-B in FIG. **5**A.

FIG. **6**A is a top view of a of a head mounted display embodiment of a near-eye display device system illustrating another thermal management solution including a multilayer graphite stack.

FIG. **6**B is a cross-section along line B-B in FIG. **6**A.

FIG. **6**C is an enlarged view of a multiple graphite layer stack.

FIG. **6**D is a cross-section of another embodiment of a multi-layer copper/graphene stack.

FIG. **7**A is a top view of a of a head mounted display embodiment of a near-eye display device system illustrating another thermal management solution including an encased graphite stack structure.

FIG. **7**B is a cross-section along line B-B in FIG. **7**A.

FIG. **7**C is an enlarged view of a first embodiment of an encased multiple graphite layer stack.

FIG. **7**D is an enlarged view of a second embodiment of an encased multiple graphite layer stack.

FIG. **7**E is a top view of a of a head mounted display embodiment of a near-eye display device system illustrating an encased graphite stack structure mounted to the exterior of the system.

FIG. **7**F is a cross-sectional view along line F-F in FIG. **7**E.

FIG. **8** is a perspective view of the first embodiment of the head mounted display device utilizing an embedded and encased graphite stack.

FIGS. **9** and **10**A are top views illustrating another thermal management solution including a buttressed frame structure.

FIG. **10**B is a cross-sectional view along line B-B in FIG. **10**A

FIG. **11**A is a side view of the thermal management solution of FIG. **9**.

FIG. **11**B is a cross-section along line B-B in FIG. **11**A.

DETAILED DESCRIPTION

Technology for thermal management of a wearable device utilized a combination of techniques to remove heat from areas of active components in the device. In one embodiment, the device is a head mounted display. One aspect of the technology includes a metal encased multilayer stack of graphite sheets which may be advantageously used as a passive thermal conductor. In the stack, each sheet has a plane high thermal conductivity along a first axis and a plane of lower thermal conductivity along a second axis. The stack is created to have a three-dimensional shape including a length and a width, and the first axis is aligned parallel to said length, the multilayer stack having a height less than the width. A first metal structure surrounds the multilayer stack of graphite sheets, with the metal structure encasing the multilayer stack along the length, width and height of the multilayer stack. The technology is optionally used in an optical mounting structure including heat generating control circuitry and housing a display optical system coupled to the control circuitry. The optical mounting structure may include first and second temple arms extending away from the control circuitry and the display optical systems. The metal encased multilayer stack of graphite sheets is thermally bonded to the control circuitry and to an exterior surface of the optical mounting structure.

The technology will be described with reference to a see-through head mounted display device, and the issues attending thermal management in such a device. It will be recognized that the thermal management techniques described herein may be expanded to alternative wearable technology, as well as any devices where thermal management using passive heat transfer technology would be useful.

Head-mounted displays, like other high powered computing devices produce large amounts of heat that needs to be quickly and efficiently directed away from the source and dissipated into the environment. This is useful in wearable devices as the surface/skin temperature of the device affects the usability and comfort of the user. There are a number of effective methods for transferring and dissipating heat currently used in the electronics industry. Traditional methods for cooling high powered electronics include passive cooling methods that are generally bulky and heavy and not particularly suitable for being used in wearable devices. In addition, typical materials used in cases (e.g. polycarbonate, LCP) have very poor thermal properties and create inefficiencies in the thermal system as a whole. Improving even small inefficiencies in the thermal system will allow for better device performance and longevity over all.

FIG. **1** is a block diagram depicting example components of a waveguide display implemented in a Near Eye Display (NED) system **8** including a compact projection light engine and diffractive waveguide. In the illustrated embodiment, a NED device system **8** includes a near-eye display (NED) device in a head-mounted display (HMD) device **2** and companion processing module **4**. HMD **2** is communicatively coupled to companion processing module **4**. Wireless communication is illustrated in this example, but communication via a wire between companion processing module **4** and HMD **2** may also be implemented. In an embodiment, HMD **2** includes a NED device having a projection light engine **120** and near-eye display **14** having a waveguide.

In this embodiment, HMD **2** is in the shape of eyeglasses having a frame **115**, with each display optical system **141** and **14***r* positioned at the front of the HMD **2** to be seen through by each eye when worn by a user. Each display optical system **141** and **14***r* is also referred to as a display or near-eye display **14**, and the two display optical systems **141** and **14***r* together may also be referred to as a display or near-eye display **14**. In this embodiment, each display optical system **141** and **14***r* uses a projection display in which image data (or image light) is projected into a user's eye to generate a display of the image data so that the image data appears to the user at a location in a three dimensional FOV in front of the user.

In this embodiment, frame **115** provides a convenient eyeglass frame holding elements of the HMD **2** in place as well as a conduit for electrical and thermal connections. In an embodiment, frame **115** provides a NED device support structure for a projection light engine **120** and a near-eye display **14** as described herein. Some other examples of NED device support structures are a helmet, visor frame, goggles support or one or more straps. The frame **115** includes a nose bridge **104**, an optical system structure or housing **131** (including a left side housing **131***l* and right side housing **131***r*) joined by the nose bridge **104**, a front top cover section **117**, a respective projection light engine housing **130** for each of a left side housing (**130***l*) and a right side housing (**130***r*) of HMD **2** as well as left and right temples or side arms **1021** and **102***r* which are designed to rest on each of a user's ears. In this embodiment, nose bridge **104** includes a microphone **110** for recording sounds and transmitting audio data to control circuitry **136**. On the exterior of the side housing **1301** and **130***r* are respective outward capture devices **113***l* and **113***r* (such as cameras) which capture image data of the real environment in front of the user for mapping what is in a FOV of a near-eye display (NED) device. The frame components **115**, **117**, **104**, **130**, **131** comprise an optical mounting structure for the display optical systems **14** and the sensors including microphone **110** and cameras **113**.

In this embodiment, dashed lines **128** are illustrative examples of some electrical connection paths which connect to control circuitry **136**, also illustrated in dashed lines. One dashed electrical connection line is labeled **128** to avoid overcrowding the drawing. The electrical connections and control circuitry **136** are in dashed lines to indicate they are under the front top cover section **117** in this example. As noted in the drawings, the control circuitry and other electronic components such as the displays are mounted to interior surfaces of the optical mounting structure or housing. There may also be other electrical connections (not shown) including extensions of a power bus in the side arms for other components, some examples of which are sensor units including additional cameras, audio output devices like earphones or units, and perhaps an additional processor and memory. Some examples of connectors **129** as screws are illustrated which may be used for connecting the various parts of the frame together.

The companion processing module **4** may take various embodiments. In some embodiments, companion processing module **4** is in a portable form which may be worn on the user's body, e.g. a wrist, or be a separate portable computing system like a mobile device (e.g. smartphone, tablet, laptop). The companion processing module **4** may communicate using a wire or wirelessly (e.g., WiFi, Bluetooth, infrared, an infrared personal area network, RFID transmission, wireless Universal Serial Bus (WUSB), cellular, 3G, 4G or other wireless communication means) over one or more communication network(s) **50** to one or more network accessible computing system(s) **12**, whether located nearby or at a remote location. In other embodiments, the functionality of the companion processing module **4** may be integrated in software and hardware components of HMD **2**.

Image data is identified for display based on an application (e.g. a game or messaging application) executing on one or more processors in control circuitry **136**, companion processing module **4** and/or network accessible computing system(s) **12** (or a combination thereof) to provide image data to near-eye display **14**.

FIG. **2**A is a block diagram of example hardware components including a computing system within control circuitry of a NED device. Control circuitry **136** provides various electronics that support the other components of HMD **2**. In this example, the control circuitry **136** for a HMD **2** comprises a processing unit **210**, a memory **244** accessible to the processing unit **210** for storing processor readable instructions and data. A network communication module **137** is communicatively coupled to the processing unit **210** which can act as a network interface for connecting HMD **2** to another computing system such as the companion processing module **4**, a computing system of another NED device or one which is remotely accessible over the Internet. A power supply **239** provides power for the components of the control circuitry **136** and the other components of the HMD **2** like the capture devices **113**, the microphone **110**, other sensor units, and for power drawing components for displaying image data on near-eye display **14** such as light sources and electronic circuitry associated with an image source like a microdisplay in a projection light engine.

The processing unit **210** may comprise one or more processors (or cores) such as a central processing unit (CPU) or core and a graphics processing unit (GPU) or core. In embodiments without a separate companion processing module **4**, processing unit **210** may contain at least one GPU. Memory **244** is representative of the various types of memory which may be used by the system such as random access memory (RAM) for application use during execution, buffers for sensor data including captured image data and display data, read only memory (ROM) or Flash memory for instructions and system data, and other types of nonvolatile memory for storing applications and user profile data, for example. FIG. **2**A illustrates an electrical connection of a data bus **270** that connects sensor units **257**, display driver **246**, processing unit **210**, memory **244**, and network communication module **137**. Data bus **270** also derives power from power supply **239** through a power bus **272** to which all the illustrated elements of the control circuitry are connected for drawing power.

Control circuitry **136** further comprises a display driver **246** for selecting digital control data (e.g. control bits) to represent image data that may be decoded by microdisplay circuitry **259** and different active component drivers of a projection light engine (e.g. **120** in FIG. **2**B). A microdisplay, such as microdisplay **230** shown in FIG. **3**C, may be an active transmissive, emissive or reflective device. For example, a microdisplay may be a liquid crystal on silicon (LCoS) device requiring power or a micromechanical machine (MEMs) based device requiring power to move individual mirrors. An example of an active component driver is a display illumination driver **247** which converts digital control data to analog signals for driving an illumination unit **222** which includes one or more light sources, such as one or more lasers or light emitting diodes (LEDs). In some embodiments, a display unit may include one or more active gratings **253**, such as for a waveguide, for coupling the image light at the exit pupil from the projection light engine. An optional active grating(s) controller **249** converts digital control data into signals for changing the properties of one or more optional active grating(s) **253**. Similarly, one or more polarizers of a projection light engine may be active polarizer(s) **255** which may be driven by an optional active polarizer(s) controller **251**. The control circuitry **136** may include other control units not illustrated here but related to other functions of a HMD **2** such as providing audio output, identifying head orientation and location information.

FIG. **2**B is a top view of an embodiment of a near-eye display **141** being coupled with a projection light engine **120** having an external exit pupil **121**. In order to show the components of the display optical system **14**, in this case **141** for the left eye, a portion of the top frame cover **117** covering the near-eye display **141** and the projection light engine **120** is not depicted. Arrow **142** represents an optical axis of the near-eye display **141**.

In this embodiment, the near-eye displays **14*l*** and **14*r*** are optical see-through displays. In other embodiments, they can be video-see displays. Each display includes a display unit **112** illustrated between two optional see-through lenses **116** and **118** and including a waveguide **123**. The optional lenses **116** and **118** are protective coverings for the display unit. One or both of them may also be used to implement a user's eyeglass prescription. In this example, eye space **140** approximates a location of a user's eye when HMD **2** is worn. The waveguide directs image data in the form of image light from a projection light engine **120** towards a user's eye space **140** while also allowing light from the real world to pass through towards a user's eye space, thereby allowing a user to have an actual direct view of the space in front of HMD **2** in addition to seeing an image of a virtual feature from the projection light engine **120**.

In some embodiments, a waveguide **123** may be a diffractive waveguide. Additionally, in some examples, a waveguide **123** is a surface relief grating (SRG) waveguide. An input diffraction grating **119** couples an image light from a projection light engine **120**. Additionally, a waveguide has a number of exit gratings **125** for an image light to exit the waveguide in the direction of a user's eye space **140**. One exit grating **125** is labeled to avoid overcrowding the drawing. In this example, an outermost input diffraction grating **119** is wide enough and positioned to capture light exiting a projection light engine **120** before the light exiting the projection light engine has reached its exit pupil **121**. The optically coupled image light forms its exit pupil in this example at a central portion of the waveguide.

FIG. **2**B shows half of a HMD **2**. For the illustrated embodiment, a full HMD **2** may include another display optical system **14** with another set of optional see-through lenses **116** and **118**, another waveguide **123**, as well as another projection light engine **120**, and another of outward facing capture devices **113**. In some embodiments, there may be a continuous display viewed by both eyes, rather than a display optical system for each eye. In some embodiments, a single projection light engine **120** may be optically coupled to a continuous display viewed by both eyes or be optically coupled to separate displays for the eyes. Additional details of a head mounted personal A/V apparatus are illustrated in U.S. patent application Ser. No. 12/905,952 entitled Fusing Virtual Content Into Real Content, Filed Oct. 15, 2010.

FIGS. **3**A and **3**B an alternative embodiment of the HMD layout and frame structure. Like numerals for the embodiment the representations of FIGS. **3**A and **3**B represent like parts to those parts illustrated in the embodiment of FIGS. **1-2**. FIG. **3**A is a perspective view and FIG. **3**B a top view of an HMD **2*a***.

In the embodiment of FIGS. **3**A and **3**B, frame **115** may by generally referred to as a wraparound-type frame, where the display optical systems **14** are integrated or mounted into a polymer, plastic or composite frame material comprising elements **110**, **131**, **102**. The temple or side arms **102** may be created to wrap around the head of a wearer and rest on the wearer's ears. In one embodiment, the temples are created by a forward component **102*r*1** and **102*l*1** and a rear component **102*r*2** and **102*l*2**. A mechanical adjustment **133*r***, **133*l*** may be provide between the forward and rear portions of temples **102**. In an alternative embodiment, the temples or side arms **102** may be continuous. Control circuitry **136** is located to be in a similar position in the embodiment of FIGS. **3** and **4** with respect to the embodiment of FIGS. **1** and **2**.

Those skilled in the art will readily understand that electronic components and circuitry utilized in the systems **2** and **2*a*** operate more efficiently when cooling takes place between the circuits and the ambient environment. In a system **2** and **2*a***, cooling components may raise ambient temperatures of the structural components to a temperature higher than the ambient but insufficient for a wearer to notice. For example, an exemplary temperature range imperceptible to a human wearer would be less than 50 deg. F.

In order to provide passive heat dissipation, various techniques and combinations thereof may be utilized.

Nanocarbon Infused Frame Elements

In one embodiment, carbon nanoparticles are mixed with the frame material to provide efficient passive heat transfer within the device frame **115** including framecomponents **102**, **130 131**, **110**, and **115**. The carbon nanoparticles increase the thermal conduction properties of the frame elements and provide a lightweight way of increasing the thermal conduction of a base material such as a polymer used to create the frame. A number of heat emitting electrical components, such as the control circuitry and power supplies discussed above, are included in the device. The techniques discussed herein provide various means for removing heat from the heat emitting electrical components in a wearable device.

Carbon nanoparticles, nanodots or nanopowder may comprise spherical high surface area graphitic carbon. Carbon nanoparticles may comprise graphene, and in particular single layer graphene (SLG), bilayer graphene (BLG), few layer graphene (FLG), multilayer graphene (MLG) carbon nanotubes, pyrolytic graphite flakes or any other nanocarbon geometries. Carbon nanoparticles may range in size from 10-100 nanometers (nm) in diameter with a specific surface area in the 2-50 m2/g. Carbon nano-particles are available in passivated and high purity, and coated and dispersed forms.

Frames such as those illustrated in FIGS. **1**-**3**B may be formed of molded polymers from any of a number of thermoplastic polymers, including, for example acrylonitrile butadiene styrene plastic (Acrylonitrile Butadiene Styrene, ABS), which has a high degree of rigidity and plasticity characteristics. Plastic is plasticized styrene (Polymerising Styrene), propylene (Acrylonitrile) and polybutadiene (Polybutadiene) mixed into butadiene rubber (Latex). The base material may have added thereto and amount of 2-10% loading by volume of carbon nanoparticles, nanopowder, pyrolytic graphite flakes or carbon nanotubes. Adding the carbon material to the material matrix prior to formation process for components **102**, **130**, **131** improves the thermal conductivity of each of the components. In the process, the carbon nanoparticles can be added simultaneously additives such as stabilizers, lubricants and coloring materials. It will be appreciated that any suitable polymer material which may be formed into a desired shape and which when cooled provides a suitable rigidity to ensure stability for the optical platform (display systems **14**) under various wearable conditions can be used. The percentage by concentration of the carbon nanoparticles may be in a range of 2 to 10% and in a range of 2-4% loading by volume.

The nanocarbon infused structural components may be used in conjunction with any of the later described thermal management techniques described herein.

Formation of frame parts in accordance with a method of the present technology includes the use of injection molding and extrusion molding techniques to form the molded parts for the frame **115**. In order to create a part such as temple **102***r* or **102***r***1**, an injection molding process includes steps of: (1) providing an injection molding apparatus; (2) mixing the base polymer pellets or powder comprising the fame material and carbon microparticles uniformly; (3) obtaining the mixture from step (2) and adding the mixture to the injection molding apparatus including a heating cylinder; (4) melting the mixture at high temperature to create a molten mixture; (5) injecting the molten mixture through an injection nozzle into a closed mold cavity; (6) and cooling the molten mixture in a mold to solidify the desired component. An extrusion process includes (1) providing a extrusion molding device; (2) mixing the engineering polymer pellets or powder comprising the fame material and carbon nanosphere particles uniformly; (3) obtaining the mixture; (4) melting the mixture at high temperature; and (4) forming a molten mixture through a die; and cooling the molten mixture in a mold to solidify the desired part.

In accordance with the present technology, at least temples **102***r***1** and **102***l* may be formed of nanocarbon infused materials. In a further embodiment with respect to HMD **2***a*, at least elements **102***r***1** and **102***l***1** are formed of nanocarbon infused materials. It will be readily understood that any of the components **102**, **117**, **130**, **131** may be formed of nanocarbon infused materials. In a further embodiment, elements **102***r***2** and **102***l***2** are formed of nanocarbon infused materials.

In alternative embodiments, the carbon nanoparticles may comprise pyrolytic graphite flakes or carbon nanotubes. In any embodiment, the frame may comprise a polycarbonate with a 2%-4% loading by volume of mono-layer graphene flakes with a very large aspect ratio to replace glass-filled polycarbonate. The current material is being used for its robustness, strength and ability to be injection molded. The graphene doped polymer possesses all the same increased properties mechanically, but also boasts a high increase in thermal properties. The increased thermal conductivity of the doped polymer will allow for better heat spreading on the surface on the device, resulting in lower touch temperatures as well as more efficient thermal dissipation from the electronics and display.

Graphene doped polymers, unlike other filled polymers, also create electrically conductivity. As such, the amount of graphene and type (shape-factor, size of flakes, number of atomic layers, aspect ratio, etc.) can be custom tailored to meet the needs of the product and sub-assemblies with respect to EMI shielding.

Bonded Graphite Layer

A further embodiment of the present technology utilizes graphite or graphene thermal pseudo-heat pipe to remove heat from the active circuitry **136**. FIGS. **4**A-**5**B represent an embodiment of a wearable device utilizing the present technology.

Graphites possess anisotropic structures and thus exhibit or possess many properties that are highly directional e.g. thermal and electrical conductivity and diffusion. Graphites are made up of layer planes of hexagonal arrays or networks of carbon atoms. These layer planes of hexagonally arranged carbon atoms are substantially flat and are oriented or ordered so as to be substantially parallel and equidistant to one another. The substantially flat, parallel equidistant sheets or layers of carbon atoms, usually referred to as graphene layers or basal planes, are linked or bonded together and groups thereof are arranged in crystallites. As used herein, the term "graphene" or "graphene film" denotes the atom-thick carbon sheets or layers that stacks up to form cleavable layers (or mica-like cleavings) in graphite.

Graphite may be made up of a plurality layers or planes. A heat sink design can be a complex task requiring extensive math—finite element analysis, fluid dynamics, etc. In designing heat sinks, various factors are taken into consideration, including thermal resistance, area of the heat sink, and the shape of the heat sink.

Some types of graphite, such as pyrolytic graphite, are available in a sheet form, which has a high thermal conductivity in the plane of the sheet and a lower thermal conductivity perpendicular to the plane of the sheet. In one form, the pyrolytic graphite is oriented such that the high-conductivity plane lies parallel to the direction of heat transfer (away from the active circuitry **136** and toward the ends of temples **102**.

In one embodiment, a graphite layer contacts at least a portion of the active circuitry **136** and is routed to an exterior portion of the frame **115**. As used herein, the term "graphite layer" refers to at least one graphene layer. A graphite layer may in some embodiments comprise a sheet of pyrolytic graphite.

FIG. **4**A illustrates an attached graphite layer **402** (comprising a left side layer **402*l*** and right side layer **402*r***) provided on the HMD **2** in the embodiment of FIG. **1**. FIG. **4**B is a cross-section of the graphite layer **402** applied to the temples **102** of the frame **115**. It will be understood that a thermal coupling of graphite or another thermally conductive material may be routed from the circuitry **136** to the graphite layer **402**. As seen in the cross-section of FIG. **4**B, the layer may be applied to the side of the temples **102** and/or to the top of the temple. Other configurations of the graphite layer **402** will be understood to be within the scope of the present technology, including providing the layer **402** on three sides of the frame and providing the layer **402** on all four sides of the frame. The technology is not limited to the shape of the frame, nor the particular nature of the wearable device.

FIG. **5**A illustrates an attached graphite layer **404** utilized in the HMD **2**A. As illustrated therein, graphite layer **404** (comprising a left side layer **404*l*** and right side layer **404*r***) are attached to temples **102** (and in particular portions **102/1** and **102*r*1**, respectively). A portion **404*r*'** and **404*l*'** of each graphite layer engages circuitry **136**, with the layer attached to the exterior of the temples **102/1** and **102*r*1**. As illustrated in FIG. **5*b***, the graphite layer **404** is secured to the exterior wall of each temple (in this view, temple **102*r*1**).

In one embodiment, the graphite layer may comprise pyrolytic graphite. Pyrolytic graphite is a form of graphite manufactured by using a raw material of a highly crystalline polymer. The polymer is put through a pyrolysis process devoid of oxygen. Not having oxygen keeps combustion from occurring and instead all the volatiles present in the polymer chains are released and resulting in a base structure of carbon rings. High temperature and pressure annealing then occurs to wedge those polymer backbones of carbon into a layered sheet structure viable for high thermal conductivity. The material is grown onto a substrate giving it a layered composition and may have different properties in different planes. Commercially available pyrolytic graphite is available in conductivities ranging from 700 W/mk to 2000 W/mK and in sheet thicknesses ranging from 10-150 μm.

It should be understood that "pyrolythic graphite" may include "thermal pyrolytic graphite" as well as "highly oriented pyrolytic graphite", and "compression annealed pyrolytic graphite," referring to graphite materials consisting of crystallites of considerable size, the crystallites being highly aligned or oriented with respect to each other and having well ordered carbon layers or a high degree of preferred crystallite orientation, with an in-plane (a-b direction) thermal conductivity greater than 1,000 W/m−K. In one embodiment, the TPG has an in-plane thermal conductivity greater than 1,500 W/m−K

The graphite layer may be selected from any material having a high thermal conductivity including pyrolytic graphite, thermal pyrolytic graphite, compression annealed pyrolytic graphite, thermal pyrolytic graphite, highly ordered pyrolytic graphite, pyrolytic graphite, and the like.

In one embodiment, the graphite layer is attached to the temples **102** using a suitable adhesive material. In one embodiment, it is desirable to attach the graphite under constraints which would not adversely affect the sensitive components of the electronics or sensors, nor the mechanical stability of the frame. Because the components (such as cameras **113** and microphone **110** may be sensitive to misalignment if frame **115** becomes mechanically distorted, post-processing of the frame **115** to apply the graphite layer may adversely affect the performance of the device **2**/**2*a***.

Graphite layers **402**, **404** may be secured to HMDs **2**/**2**A using any suitable form of adhesive to bond the graphite layer to the material comprising the frame elements. Suitable adhesive materials include, for example, inorganic and organic adhesives. An exemplary adhesive material is an epoxy. In one embodiment, the bonding material exhibits thermal conductivity properties, e.g., a thermally conductive epoxy. Acrylic adhesives may also be utilized.

Suitable graphite layers include pyrolytic graphite sheets available from Panasonic Corporation. Such sheets may include applications with or without acrylic adhesives and adhesive tapes.

In one embodiment, the graphite layer may be preformed into a shape suitable for application to the frame elements and which may be thermally connected to the control circuitry **136** or other electronic components of an HMD.

In another alternative, graphene may be grown or laminated on one or more surfaces of the frame. Graphene may be applied by any of a number of methods, including by chemical vapor deposition (CVD), SiC thermal decomposition, or a graphene oxide reduction. In a CVD method, a film comprising graphene is formed on one surface of a substrate (which may comprise a portion of the frame) the graphene film tailored for the particular use by the process chosen.

Nanocarbon Infused Frame with Graphite Layer

A further embodiment of the present technology includes the use of nanocarbon infused frame elements with an applied graphite layer.

The combination of the graphite layer in conjunction with the nanocarbon infused material increases the thermal conduction properties of the frame **115**. It will be readily understood that any of the components **102**, **117**, **130**, **131** may be formed of nanocarbon infused materials.

In accordance with the present technology, at least temples **102*r*** and **102*l*** may be formed of nanocarbon infused materials and have applied thereto a graphite layer in accordance with the foregoing embodiments wherein the graphite layer bonds to a surface of the temple **102/1** and **102*r*1**. In a further embodiment, elements **102**R**2** and **102**L**2** are formed of nanocarbon infused materials.

Graphite layers **402**, **404** may be secured each other using any suitable form of adhesive to bond the graphite layers to each other, and the stack to the material comprising the frame elements. Suitable adhesive materials include, for example, the inorganic and organic adhesives provided above including epoxy. In one embodiment, the bonding material exhibits thermal conductivity properties, e.g., a thermally conductive epoxy. Acrylic adhesives may also be utilized. Suitable graphite layers include any of the pyrolytic graphite materials discussed herein and may include pyrolytic graphite sheets available from Panasonic Corporation. Such sheets may include applications with or without acrylic adhesives and adhesive tapes. In one embodiment, the adhesives used are curable at ambient temperatures in a range of 60-80 degrees Fahrenheit.

It will be understood that the application of a graphite layer in combination with the nanocarbon infused frame elements may further be enhanced by use of any of the below thermally conductive graphite structures described herein.

In order to create a part such as temple **102***r* or **102***r***1**, use of the injection molding and/or extrusion process discussed above may be utilized. Following the aforementioned cooling steps, the graphite layer may be applied to the desired location of the part by (1) forming the graphite layer into a suitable shape for application to the part surface, (2) applying one of the aforementioned adhesives to the frame element in a contact region; (3) applying the graphite layer and (4) applying a uniform pressure to the graphite layer to allow curing of the adhesive to secure the layer to the part.

Graphite Layer Stack

A further embodiment of the present technology includes the use a multi-layer stack of graphite layers constructed to be applied to the surface of the elements. Construction of a multi-layer stack of graphite sheets may provide a thermal highway which can be attached to components of the HMD **2**/**2***a*.

FIGS. **6**A-**6**C illustrates use of the multilayer stack in conjunction with the graphite layer thermally coupled to the active circuitry **136**. FIG. **6**A illustrates one configuration of the multiple graphite layer stack in accordance with the technology applied to frame elements of an HMD device and thermally coupled to active circuits in HMD **2***a*. In FIG. **6**A, two stacks **600***r* and **600***l* are illustrated

A representation of a multilayer stack of graphite layers is illustrated in FIG. **6**C. In FIG. **6**C, individual graphite layers **602**-**608** are secured to and sandwich adhesive layers **612**-**616**. While four graphite layers are illustrated, any number of graphite and adhesive layers may be utilized to make stack **600**.

One difficulty in assembling stack **602** is that graphite layers by nature not wish to adhere to each other. In addition, granites may be tear sensitive, and the structure can be brittle when applied to the exterior of a frame which can be exposed to ambient conditions. Suitable adhesive materials include, for example, inorganic and organic adhesives. An exemplary adhesive material is an epoxy. In one embodiment, the bonding material exhibits thermal conductivity properties, e.g., a thermally conductive epoxy. Acrylic adhesives may also be utilized. Suitable graphite layers include any of the pyrolytic graphite materials discussed herein. The graphite stack **602** can be formed into any of a number of three-dimensional shapes by configuring the graphite layers assembled into the stack.

In one embodiment, a stack **600** is not coupled by portions **404***r*' and **404***l*' to the active circuitry **136**, but is attached to any one or more of the surfaces of the frame components such as temples **102**, cover section **117**, and housing **131**.

It will be understood that the application of a graphite layer stack may be utilized in combination with the nanocarbon infused frame elements discussed above.

In order to create a part such as temple **102**/**1** or **102***r***1**, use of the injection molding and/or extrusion process discussed above may be utilized. Prior to formation of the part or thereafter, a multi-layer stack is created by creating the multilayer stack **600** including (1) forming the graphite layers into a suitable shape to be applied to the surface of a frame element; (2) applying adhesive to a first of the graphite layers followed by (3) applying a second graphite layer on the adhesive; (4) applying uniform pressure to the graphite layer; and (optionally) (5) repeating steps (1)-(3) for any number of additional layers. Alternatively, steps (1)-(3) may be repeated for any number of layers prior to applying uniform pressure to the outermost layer in the stack. Thereafter, the stack **600** is applied to a frame part using any of the aforementioned adhesives discussed herein. The part may be created with any of the materials discussed herein and any of the aforementioned part fabrication processes, with or without infused nanocarbon in the part material.

A thermal coupling structure of graphite (such as region **404***r*') may be incorporated during stack formation or glued to the stack **600** thereafter.

Although the graphite layer is illustrated in a particular configuration in FIGS. **6**A-**6**C, the layers may be provided in any of a number of regions on the device. Any surface of the temples **102** may include a graphite layer (whether coupled to a thermal coupling or attached to the device to promote heat transfer away from any active components).

In some embodiments, the resulting structure is a flexible structure that can be molded to a surface of the frame, as illustrated, or used in any of a number of applications. The flexibility of the structure and the thermal performance of the structure depends on the bonding layers between the graphite layers.

An alternative embodiment of a graphite layer structure may be formed as a copper-graphene structure **650**. In this embodiment, a central, planer sheet of copper **656** having a thickness ranging from 20-50 μm is coated on both sides with layers of graphene **654**, **658** after which copper layers **652**, **660** are applied to respective graphene layers **654**, **658**. The graphene may be formed by any of the aforementioned processes and layers **652** and **660** of copper may be deposited by a suitable vapor or physical deposition process.

Encase Graphite Layer Stack

A further embodiment of the present technology includes the use a multi-layer stack of graphite layers constructed within a metallic enclosure which may be thermally connected to active circuitry and thereafter applied to the surface of frame elements to act as a passive pseudo-heat pipe.

FIGS. **7**-**8** illustrate a multilayer stack of graphite constructed in an enclosed metallic casing. In one embodiment illustrated in FIG. **7**D, an encased assembly **750** including the graphite stack **700***a* may have a structure similar to graphite stack **600** illustrated above. This embodiment, plurality layers **702** through **708** are joined by adhesives **712**-**716** after which the stack **700***a* is encased in a metallic layer or coating. FIG. **7**C illustrates an alternative embodiment of an encased assembly **750** including stack **700***b* wherein no adhesive is used between the multiple graphite layers. In the embodiment of FIG. **7**C, direct contact between the layers **702**-**708** and the casing material ensures thermal conduction.

The embodiment of FIG. **7**D may be created by: (1) forming a first graphite layer into a suitable shape to be applied to the surface of a frame element; (2) applying adhesive to a first of the graphite layers followed by (3) applying a second graphite layer on the adhesive; (4) applying uniform pressure to the graphite layer; and (optionally) (5) repeating steps (1)-(3) for any number of additional layers. Alternatively, steps (1)-(3) may be repeated for any number of layers prior to applying uniform pressure to the outermost layer in the stack. After creation of stack **700***a*, the stack is encased in a metallic casing **715**. The casing **715** is preferably made of a high conductivity metal such as titanium, copper, tin, nickel, silver, aluminum, TiW (90/10, and other alloys), copper tin alloys, and alloys of the above metals). The casing extends around and encloses the pyrolytic graphite stack so that the pyrolytic graphite stack is embedded within the casing. In one embodiment, the casing is hermetic, so that no external agents can penetrate to contact the stack. The casing may be applied by metallic deposition techniques or formed by mechanically manipulating workable forms of the aforementioned metals to encase the stack **700***a*.

The embodiment of FIG. **7**C may be created by: (1) forming a selected number of the graphite layers to be formed into the stack into a suitable shape to be applied to the frame element; (2) providing the graphite layers and the coating material in a vacuum environment; (3) stacking successive graphite layers into a stack **700***b*; (4) applying uniform pressure to the graphite layers; and encasing the graphite layers in the stack using one of (a) metallic deposition onto the stack or (b) mechanical manipulation of metal plates of sufficient size to surround the stack followed by sealing the casing about the stack **700***b*.

Suitable graphite layers include any of the pyrolytic graphite materials discussed herein. The graphite material used in the stack should have its high plane of conductivity arranged and oriented perpendicular to the plane of the drawings of FIGS. **7**C and **7**D so that when arranged in the device **2**, high-conductivity plane lies parallel to the direction of heat transfer (away from the active circuitry **136** and toward the ends of temples **102**).

FIG. **7**A is a top view of the HMD device to a illustrating that the encased graphite layer stack structure can be incorporated into the frame materials of the device. Corporation the frame materials is also illustrated with respect to device two in FIG. **8**. In this embodiment, the case stack, illustrated in Figures of be, is molded into the frame itself. FIGS. **7**E and **7**F illustrate positioning of the encased structure on a top portion of the device two a.

Various configurations of the encased graphite layer stack structure can be utilized in accordance with the teachings of this technology. The structure may have various different three-dimensional forms, an alternative components of the forms may be joined together. As illustrated in FIG. **7**D, two such structures may be formed in a linear manner and joined together using any of the aforementioned techniques of adhesive, creating the structures from native graphite sheets, or the like.

With respect to FIGS. **7**A and **7**C, each encased structure may have a length L, width W and height H defined in accordance with the thermal management objectives of the system. Each of the respective sheets of graphite in the layer stack may be defined and selected to have a plane high thermal conductivity along a first axis and a plane of lower thermal conductivity along a second axis. In one embodiment the plane is selected so that the axis of high conductivity aligns with the length and is parallel to an axis bisecting the length of the encased stack. As noted in FIG. 7A, the length is multiple times longer than the width the height less than the width.

FIGS. **7**E and **7**F illustrate the encased structure **752** positioned on an exterior surface of an HMD **2***a*. In the illustration of FIGS. **7**E and **7**F, the encased structure **752** is positioned on a top surface **910** of arm **102***r***1**. It should be understood that the structure **752** may be provided on a bottom surface **912** or a side surface **914** of the arm. In addition, FIG. **7**E illustrates two encased structures **752** joined at an interface **753**. Due to the workability of the metal encasing the structure **752**, joining of respective structures may occur by thermal bonding such as mechanically connecting, soldering or welding the respective structures **752**, or by forming the underlying graphite layers in to an angled structure and thereafter encasing the formed angled structure in a metal coating.

It will be understood that the application of a graphite layer stack may be utilized in combination with the nanocarbon infused frame elements discussed above. In addition, the encased structure may be utilized with the stack **600** described above, alone or in combination therewith.

Buttressed Frame Structure

FIGS. **9-11** illustrate an alternative frame structure suitable for use with any of the aforementioned devices **2** and **2***a*. Although the subject matter will be illustrated with respect to the HMD **2***a*, it will be recognized that similar techniques can be used with any type of framing structure.

In FIGS. **9-11**B, temples **102**R**1** and **102**L**1** have been formed to include voids **900**, **902**, thereby creating arches adjacent the joining points of the temples **102***r***1** and **101**L**1** to temples **102**R**2** and **102**L**2**, respectively, and housing **131**. The voids effectively provide a arched temple structure which couples the housing **131** two other portions of the side arms **102**L**2**/**102***r***2**. Voids **900**, **902** provide an increase in the surface area available for convective and radiant heat transmission to the ambient environment. Any heat provided and transferred from the active circuitry to the temples **102**R**1** and **102**/**1** can be more easily cooled by the ambient environment. In the illustrated embodiment, void **900** includes a first sidewall **912**, second sidewall **914** and two arches **916**, **918** joining the respective sidewalls

In addition, the voids **900**, **902** increase the strength of the temples **102** by using arch construction techniques. An arch is a pure compression form resolving forces into compressive stresses and, in turn eliminating tensile stresses. Given the architecture of HMDs **2**/**2***a*, with forward components carrying most of the weight and support components (such as the temples **102**) stabilizing the device, strength in the temple components in combination with lightweight constructions is desirable.

Although the voids are illustrated as being provided only in elements **102***r***1** and **102**/**1**, it will be understood that the voids may be formed in temple portions **102**R**2** and **102**L**2**, or in a unitary temple structure such as that provided in the HMD device **2**.

In addition, the void architecture of FIGS. **9** and **10***a* can be utilized with any of the aforementioned thermal management techniques described above.

In particular, the components of the device of FIG. **9** may be manufactured of nanocarbon infused materials as described above. Any one or more of the graphite structures discussed above may be attached on the surface of or embedded in the structures of FIG. **9**.

FIG. **10**A illustrates an example of using a graphite layers to that described above in FIG. **5**A in combination with the voids **900**, **902**. As illustrated therein, a graphite layer **404** is provided as in FIG. **5**A with portions **404***r* and **404***l* being attached to elements **102***r***1** and **102**/**1** having voids therein. Graphite layers **404***r* and **404***l* may be a sheet of pyrolytic graphite, any of the graphite stacks illustrated herein, or a laminated layer of graphene.

FIG. **10**B illustrates a cross-section along line B-B in FIG. **10**A, showing the top surface **910**, bottom surface **912**, first side **914** and second side **916** of arm portion **102***r***1**. In addition, the interior walls **918** and **912** are illustrated. It will further be appreciated that graphite layer or layers may be applied to the interior walls **918**, **920** of the structure of FIG. **10**A. In FIG. **10**B, only void **900** is illustrated, but it should be understood that structure **752** can be provided on both arms **102**L and **102***r*

FIGS. **11**A and **11**B illustrate the use of the graphite layer structure **650** described above wherein the structure **650** is encased in the frame **2***a*. The structure **650** is thermally coupled to the heat producing components and extends into the void regions **900**, **902** (In FIGS. **11**A and **11**B, only void

902 is illustrated, but it should be understood that structure 650 can be provided on both arms 102*l* and 102*r*.)

In addition, the voids formed in components of the frame may take various shapes. The arcuate voids 900, 902 provide convection vertically when the device is worn by a wearer. This can provide convection with cooler air passing through and around the voids and frame element as it rises. However, the voids may be provided horizontally with respect to direction of the temples 102. Moreover, the voids may be provided in any number and shape. For example, a plurality of circular or other shaped bores may be provided in the frame elements

Additional graphite layers may be provided on the interior surfaces of voids 900, 902 or the outer surfaces of the temples 102.

Any one or more of the graphite layers, graphite stacks or encased structures may be embedded in the frame by manufacturing the frame components around the thermal structures. An injection molding process embedding such structures includes steps of: (1) providing an injection molding apparatus; (2) mixing the engineering polymer pellets or powder comprising the fame material and carbon nanosphere particles uniformly; (3) obtaining the mixture from step (2) and adding the mixture to the injection molding apparatus including a heating cylinder; (4) melting the mixture at high temperature; (5) providing the graphite layer, multilayer stack or encased graphite layer stack into a mold cavity and closing the cavity; (6) injecting the molten mixture through an injection nozzle into a closed mold cavity; and (7) cooling the molten mixture in a mold to solidify the desired part. An extrusion process includes (1) providing a extrusion molding device; (2) mixing the engineering polymer pellets or powder comprising the fame material and carbon nanosphere particles uniformly; (3) obtaining the mixture; (4) melting the mixture at high temperature; (4) forming a molten mixture through a die to surround a graphite layer, multilayer stack or encased graphite layer stack; and (5) cooling the molten mixture in a mold to solidify the desired part.

Aspects of Certain Embodiments

Embodiments of the technology include an apparatus comprising: a multilayer stack of graphite sheets, each sheet having a plane high thermal conductivity along a first axis and a plane of lower thermal conductivity along a second axis, the stack having a three-dimensional shape including a length and a width, and the first axis is aligned parallel to said length, the multilayer stack having a height less than the width; and a first metal structure surrounding the multilayer stack of graphite sheets, the metal structure encasing the multilayer stack along the length, width and height of the multilayer stack.

Embodiments of the technology include any for the aforementioned embodiments wherein the stack is comprised of a plurality of sheets of pyrolytic graphite.

Embodiments of the technology include any for the aforementioned embodiments wherein the metal is selected from one of: titanium, copper, tin, nickel, silver, aluminum, TiW (90/10, and other alloys), copper tin alloys, and alloys of the each of said metals.

Embodiments of the technology include any for the aforementioned embodiments wherein an uppermost layer in the stack and a lowermost later in the stack contact a respective upper and lower surface of the metal encasing layer.

Embodiments of the technology include any for the aforementioned embodiments further including a second multilayer stack and second metal encasing structure, the second metal encasing structure bonded to the first metal encasing structure by a thermally transmissive material.

Embodiments of the technology include any for the aforementioned embodiments wherein stack comprises a plurality of graphite sheets, each sheet bonded to a respective sheet using an adhesive.

Embodiments of the technology include any for the aforementioned embodiments wherein the stack comprises a plurality of graphite sheets in direct mutual contact.

Embodiments of the technology include any for the aforementioned embodiments wherein the metal structure creates a hermetic vacuum around the multilayer stack.

Embodiments of the technology include any for the aforementioned embodiments utilized in a wearable device including electronic components. The wearable device may include a mounting structure including the electronic components; and a metal encased multilayer stack of a plurality graphite sheets and thermally bonded to the electronic components, each sheet having a plane high thermal conductivity along a first axis and a lower thermal conductivity along a second axis, the stack having a three-dimensional shape including a length and a width and the first axis aligns parallel to said length, the multilayer stack having a height less than the width, the metal encasing the multilayer stack along the length, width and height of the multilayer stack.

Embodiments of the technology include any for the aforementioned embodiments of a wearable device wherein the stack is comprised of a plurality of sheets of pyrolytic graphite.

Embodiments of the technology include any for the aforementioned embodiments of a wearable device wherein the metal is selected from one of: aluminum, copper, silver, aluminum alloy, copper alloy, and silver alloy.

Embodiments of the technology include any for the aforementioned embodiments of a wearable device wherein an uppermost layer in the stack and a lowermost later in the stack contact a respective upper and lower surface of the metal encasing layer.

Embodiments of the technology include any for the aforementioned embodiments of a wearable device further including a second multilayer stack and second metal encasing the second multilayer stack, the second metal bonded to the first metal by a thermally transmissive material.

Embodiments of the technology include any for the aforementioned embodiments of a wearable device wherein each sheet bonded to a respective sheet using an adhesive.

Embodiments of the technology include any for the aforementioned embodiments of a wearable device wherein the stack comprises a plurality of graphite sheets in direct mutual contact.

Embodiments of the technology include any for the aforementioned embodiments of a wearable device wherein the first metal encases the stack to create a hermetic vacuum around the multilayer stack.

Embodiments of the technology include any for the aforementioned embodiments utilized in a head mounted display including control circuits which produce heat. The head mounted display may comprise an optical mounting structure including the heat producing electrical components, the mounting structure housing display optical system coupled to the heat producing electrical components, and first and second temple arms extending away from the heat producing electrical components and the display optical systems; and a metal encased multilayer stack of graphite sheets and thermally bonded to the heat producing electrical components and to an exterior surface of the optical mounting structure, each sheet having a plane high thermal conductivity along a first axis and a lower thermal conductivity along a second axis, the stack having a three-dimensional shape including a length and a width and the first axis aligns parallel to said length, the multilayer stack having a height less than the width, the metal structure encasing the multilayer stack along the length, width and height of the multilayer stack.

Embodiments of the technology include any for the aforementioned embodiments of a head mounted display or wearable device wherein an uppermost layer in the stack and a lowermost later in the stack contact a respective upper and lower surface of the metal encasing layer.

Embodiments of the technology include any for the aforementioned embodiments of a head mounted display or wearable device wherein the stack is comprised of a plurality of sheets of pyrolytic graphite.

Embodiments of the technology include any for the aforementioned embodiments of a head mounted display or wearable device wherein the stack comprises a plurality of graphite sheets in direct mutual contact.

Embodiments of the technology include any for the aforementioned embodiments of a head mounted display or wearable device including a means for supporting display components and heat producing electronic components along with a means for passively transmitting heat from the components, the means including one or more layers of graphite attached to the heat producing components and an exterior of the means for supporting the display components.

Although the subject matter has been described in language specific to structural features and/or acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as examples of implementing the claims and other equivalent features and acts that would be recognized by one skilled in the art are intended to be within the scope of the claims.

What is claimed is:

1. An apparatus comprising:

heat producing electrical components;

a multilayer stack of graphite sheets, individual graphite sheets having a plane of high thermal conductivity along a first axis and a plane of lower thermal conductivity along a second axis, the multilayer stack having a three-dimensional shape including a length and a width, and the first axis is aligned parallel to said length, the multilayer stack having a height less than the width;

a first rigid metal structure surrounding the multilayer stack of graphite sheets, the first rigid metal structure encasing the multilayer stack along the length, width, and height of the multilayer stack; and

a thermal connector having a first end in contact with the heat producing electrical components and a second end in contact with the encased multilayer stack of graphite sheets, the thermal connector conducting heat from the heat producing electrical components to the encased multilayer stack of graphite sheets.

2. The apparatus of claim **1** wherein the individual graphite sheets are pyrolytic graphite sheets.

3. The apparatus of claim **1** wherein a metal of the first rigid metal structure is selected from one of: aluminum, copper, silver, aluminum alloy, copper alloy, and silver alloy.

4. The apparatus of claim **1** wherein an uppermost layer in the multilayer stack and a lowermost layer in the multilayer stack contact respective upper and lower surfaces of the first rigid metal structure.

5. The apparatus of claim **1** further including a second multilayer stack of graphite sheets and second metal structure, the second metal structure bonded to the first rigid metal structure by a thermally transmissive material.

6. The apparatus of claim **1** wherein the individual graphite sheets are bonded to neighboring individual graphite sheets of the multilayer stack using an adhesive.

7. The apparatus of claim **1** wherein the individual graphite sheets are in direct mutual contact.

8. The apparatus of claim **7** wherein the first rigid metal structure creates a hermetic vacuum around the multilayer stack.

9. A wearable device, comprising:

a mounting structure including electrical components;

a multilayer stack of graphite sheets thermally bonded to the electrical components, individual graphite sheets of the multilayer stack having a higher thermal conductivity along a first axis and a lower thermal conductivity along a second axis, the multilayer stack having a three-dimensional shape including a length and a width where the first axis aligns parallel to said length, the multilayer stack having a height less than the width; and

a rigid metal structure encasing the multilayer stack to create a hermetic vacuum around the multilayer stack, the rigid metal structure encasing the multilayer stack along the length, width, and height of the multilayer stack.

10. The wearable device of claim **9** wherein the individual graphite sheets comprise pyrolytic graphite sheets.

11. The wearable device of claim **10** wherein a metal of the rigid metal structure is selected from one of: aluminum, copper, silver, aluminum alloy, copper alloy, and silver alloy.

12. The wearable device of claim **11** wherein an uppermost layer in the multilayer stack and a lowermost layer in the multilayer stack contact respective upper and lower surfaces of the rigid metal structure encasing the multilayer stack.

13. The wearable device of claim **12**, further comprising a second multilayer stack and a second metal structure encasing the second multilayer stack, the second metal structure bonded to the rigid metal structure by a thermally transmissive material.

14. The wearable device of claim **9** wherein the individual graphite sheets are bonded to respective individual graphite sheets using an adhesive.

15. The wearable device of claim **9** wherein the multilayer stack comprises a plurality of graphite sheets in direct mutual contact.

16. The wearable device of claim **9** further comprising:

a thermal connector having a first end in contact with the electrical components and a second end in contact with the rigid metal structure encasing the multilayer stack of graphite sheets, the thermal connector conducting heat from the electrical components to the rigid metal structure encasing the multilayer stack of graphite sheets.

17. A head mounted display, comprising:

electrical components comprising control circuits which produce heat;

an optical mounting structure including the heat producing electrical components, the optical mounting structure housing a display optical system coupled to the heat producing electrical components, and first and second temple arms extending away from the heat producing electrical components and the display optical system;

a metal encased multilayer stack of graphite sheets and thermally bonded to the heat producing electrical components and to an exterior surface of the optical mounting structure, each sheet of the graphite sheets having a plane high thermal conductivity along a first axis and a lower thermal conductivity along a second axis, the multilayer stack having a three-dimensional shape including a length and a width and the first axis aligns parallel to said length, the multilayer stack having a height less than the width, a metal structure encasing the multilayer stack along the length, width and height of the multilayer stack; and

a thermal connector having a first end in contact with the heat producing electrical components and a second end in contact with the metal encased multilayer stack of graphite sheets, the thermal connector conducting heat from the heat producing electrical components to the metal encased multilayer stack of graphite sheets.

18. The head mounted display of claim **17** wherein an uppermost layer in the multilayer stack and a lowermost layer in the multilayer stack contact a respective upper and lower surface of the metal structure encasing the multilayer stack.

19. The head mounted display of claim **18** wherein the multilayer stack is comprised of a plurality of sheets of pyrolytic graphite.

20. The head mounted display of claim **19** wherein the multilayer stack comprises a plurality of graphite sheets in direct mutual contact.

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